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Heat management for an internal combustion engine

The invention relates to a method for actuating a thermostat in a coolant circuit of a motor vehicle.

A genus-forming cooling system and a genus-forming method for operating the cooling system is known from DE 44 09 547 C2. With this cooling system it is possible to set two different coolant temperatures as a function of specific operating parameters of the vehicle. The influencing operating parameters are here the speed of the vehicle, the load state of the internal combustion engine and the temperature of the intake air. As a function of the abovementioned parameters, a control algorithm is used to make a decision about which temperature level the coolant is to be adjusted to. The thermostat is actuated in the coolant circuit here using a control unit in which the control algorithm is implemented. 90°Celsius or 110°Celsius are provided as temperature levels.

With a method of the generic type for operating a cooling system it is possible to operate the cooling system either at an upper high temperature level which is favorable for consumption or at a lower temperature level which enhances performance, depending on the requirements made of the internal combustion engine.

The previously known two-position controllers tend to oscillate. This problem occurs whenever the influencing variables and their evaluation lie in a value range in which when there is the slightest change in the influencing variables the control algorithm adjusts to the respective other temperature level. Furthermore, previously known methods do not take into account the external temperature, that is to say the ambient temperature, even though the ambient temperatures can

fluctuate greatly and have a large influence on the engine temperature and the possible cooling power of the cooling system in extreme weather situations. This results in the reference variables for the closed-loop control having to also contain a certain safety region. That is to say in particular with respect to the lower temperature level it is necessary for a high enough value to be selected for it so that low-pollutant operation of the internal combustion engine is also ensured even in the winter or at cold ambient temperatures. That is to say at high ambient temperatures a desired further lowering of the lower temperature level must not be carried out.

The object of the invention is therefore to specify a method for actuating a thermostat in a cooling system, in particular for a motor vehicle, which is improved in terms of avoidance of oscillation and adaptation to the ambient conditions.

The object is achieved with a method according to claim 1. Further preferred embodiments of the invention are contained in the subclaims and in the exemplary embodiments.

The solution is mainly arrived at with a control algorithm which makes it possible to adjust the coolant temperature to three different temperature levels taking into account the ambient temperature. The control algorithm is configured here as a software program and is implemented in a logic element of the engine electronics. In order to avoid oscillation as a result of excessively frequent changing of the closed-loop control setting, the control algorithm has a hold function with which the closed-loop control settings are retained for a minimum time period. New closed-loop

control parameters cannot be set again until after the minimum time period has expired.

The following advantages are mainly achieved with the invention:

By setting up three temperature levels to which the coolant temperature can be adjusted and by taking into account the ambient temperature in the decision about the temperature level to be selected it is possible both to improve the power output and reduce the consumption of an internal combustion engine. The lowest temperature level of 80°Celsius permits improved charging of the combustion chambers with an ignitable fuel mixture at hot ambient temperatures in a demand-controlled fashion. While the highest temperature level of 105°Celsius is reliably reached even at cold ambient temperatures by increasing the temperature and the internal combustion engine can thus be operated more reliably in a way which produces few pollutants even at extremely cold ambient temperatures.

Taking into account the ambient temperature in the decision process about the temperature level to be set also has the advantage that the operation of the internal combustion engine can be adapted better to the different ambient temperatures. As a result, temperature fluctuations both due to geographic influences and seasonal influences can be included in the decision about the temperature level to be set, and the internal combustion engine can be operated at a better operating point than was previously possible.

Setting a better operating point of the engine also provides the advantage of the three temperature levels to which the coolant temperature can be adjusted and which were introduced according to the invention.

The invention advantageously has a fallback level which can be resorted to if the open-loop control electronics fail or if the control algorithm operates incorrectly. The detection of faults is possible here by the self-testing of the open-loop control electronics or by monitoring the coolant temperature. The self-testing of the open-loop control electronics generates a fault signal here. If the coolant temperature which is monitored with a sensor is excessively high, a decision stage decides whether the coolant temperature lies above a critical temperature threshold and if that is the case it generates a fault signal. When the fault signal is present, the temperature closed-loop control is adjusted with a redundant PID controller, or if there is no redundant PID controller the cooling system is operated with maximum cooling power without closed-loop control.

In another advantageous embodiment of the invention, a classification of the driver type is included in the control algorithm. Classifications of the drive type are known from adaptive transmission controllers and are contained as an identifier in the engine controllers. This advantageously permits the cooling power to be adapted to the personal behavior of the driver of the vehicle. Sporty drivers tend to prefer coolant temperatures in the lower temperature range since the degree of charging of the combustion cylinders is then better and more torque and more power is available.

An exemplary embodiment of the invention will be explained in more detail below with reference to figures, of which:

fig. 1 shows a typical cooling system in a motor vehicle, and in a schematic form the actuation

of the three-way thermostat with a control unit taking into account the most important parameters for the method according to the invention,

fig. 2 shows a signal flowchart with a five-stage decision cascade in the form of a simplified Matlab-Simulink representation of the method according to the invention, and

fig. 3 shows the addition to the method according to the invention of a fallback level in the form of a signal flowchart.

Figure 1 is a schematic view of a typical cooling system for a six-cylinder internal combustion engine 1. In addition to the internal combustion engine, a vehicle radiator 2 and a heat exchanger 3 are integrated into the cooling system. The cooling power of the vehicle radiator can be influenced with an electrically driven fan 4. In order to regulate the power of the fan the electric motor of the fan is closed off and loop controlled with a control unit 5. Coolant which is cooled by means of the forward flow line 6 is removed from the vehicle radiator and fed into the cooling lines 8 for supplying the cooling ducts (not illustrated in more detail) for the combustion cylinders 9 by means of the coolant pump 7. The heated coolant is fed to the three-way thermostat 11 via return lines 10 from the combustion cylinders 9. Depending on the position of the valves in the three-way thermostat 11, the coolant passes out of the internal combustion engine via the radiator return 12 and back into the vehicle radiator or via the radiator short-circuit 13 and the coolant pump 7 and back again into the cooling lines 8 of the internal combustion engine.

Depending on the position of the valves in the three-way thermostat 11, the cooling system may be operated here, in a manner known per se, in the short-circuit operating mode, in the mixed operating mode or in the large cooling circuit. The heat exchanger 3 is connected to the high temperature branch of the cooling system in the internal combustion engine via a temperature-controlled shut-off valve 14. The throughput through the heat exchanger after the shut-off valve 14 is opened can be regulated with an additional electric coolant pump 15 and a clocked shut-off valve 16 in order to regulate the heating power.

The temperature level of the coolant in the internal combustion engine is set here by the control unit 5 under sensor control. A logic element logic in the form of a microelectronic computing unit is contained in the control unit. The control unit is preferably formed by the control unit of the engine electronics. The control algorithm outlined in figures 2 and 3 is implemented in the form of a software program in the logic element. The most important operating data as input variables for the control algorithm are in this context: the quantity of fuel introduced into the combustion cylinder, the engine speed, the temperature of the intake air, the temperature of the external air, the classification of the driver type and the speed of the vehicle.

The quantity of fuel can be determined in direct-injection engines by means of the measured and controlled injection quantity FJRAT. In the case of carburetor engines the quantity of fuel is determined indirectly by means of the measured intake airflow MAF (Mass Air Flow) and the stoichiometric fuel/air ratio. The abovementioned operating data is usually present in engine control units or is sensed and collected by them

in order to control the combustion process. Classifications of the driver type are used, for example, in vehicles with adaptive automatic transmissions. The display of the external air temperature on a display in the interior of the vehicle is customary nowadays in vehicles of the present applicant. So that existing engine electronics and existing engine control software can be resorted to in order to carry out the invention and no additional expenditure is necessary to prepare or determine the operating data of the internal combustion engine.

Fig. 2 shows a simplified Matlab-Simulink representation of the software architecture and the signal flowchart for determining according to the invention the coolant temperature to be set. The input signals comprising the temperature 21 of the intake air, mass air flow 22, classification 23 of the driver type, engine speed 24, fuel injection quantity 25 and temperature 26 of the external air are further processed with a five-stage decision cascade and the coolant setpoint temperature 27 which is matched to the current operating parameters is determined therefrom. Each stage of the decision cascade is composed of an EDP program for deciding and calculating a setpoint temperature as a function of the program input variables. The individual software programs are referred to below as modules.

The five-stage decision cascade is composed here in engines with port injections of the modules KE_ECT (for Kanaleinspritzer [port injector] Engine Cooling Temperature), ECT_FTK (for Engine Cooling Temperature after Fahrertypklassifizierung [classification of driver type]), ECT_AT (for Engine Cooling Temperature after Ansauglufttemperatur [intake air temperature]), ECT_VehSpd (for Engine Cooling Temperature Vehicle

Speed) and the module ECT_ExtAir (for Engine Cooling Temperature External Air Temperature).

In engines with direct injection, the quantity of fuel is determined from the injection quantity. In these engines, the module DE_ECT (for Dierekteinspritzung [direct injection] Engine Cooling Temperature) is used for calculating a first coolant setpoint temperature TMSoll1 instead of the module KE_ECT. The control algorithm contains on a standard basis both modules, for the port injector as well as for the direct injector. Which module is used is set on an engine-specific basis by activating one of the two modules by means of a program. This selection possibility is represented in the signal flowchart according to fig. 2 by means of the switching element 28. This procedure has the advantage that only one control algorithm has to be implemented for the various types of mixture formation and said algorithm can then be set to the respective engine version.

The first coolant setpoint temperature TMSoll1 which is calculated from the fuel input is load dependent, that is to say is set to 105°Celsius or to 80°Celsius as a function of the engine speed EngSpd and the quantity of fuel. The first coolant setpoint temperature TMSoll1 is weighted using the following module ECT_FTK as a function of the current classification FTK of the driver type from the engine controller and either a coolant temperature of 105°Celsius or of 80°Celsius is preferred therefrom in accordance with the classification of the driver type.

The coolant temperature of 80°Celsius is weighted to a greater extent, i.e. is selected with preference, for a sporty classification of the driver type. The result of

this weighting is a second coolant setpoint temperature TMSoll2.

After the classification of the driver type, the temperature of the intake air is taken into account in the next stage of the decision cascade. This is done in the module ECT_AT. The sensing of the temperature of the intake air serves to detect a congestion situation. If the motor vehicle is in congestion, it is desired to lower the coolant setpoint temperature to 80°Celsius or 90°Celsius, which is triggered by this congestion. This is complied with by lowering the coolant temperature to one of the two abovementioned values if the temperature of the intake air exceeds a reference value from the temperature interval 40°Celsius to 50°Celsius. The result, after taking into account the temperature of the intake air, is the coolant setpoint temperature TMSoll3.

This coolant setpoint temperature TMSoll3 which is determined is evaluated in the decision cascade by means of the next module ECT_VehSpd using the current speed of the vehicle. If the speed of the vehicle exceeds the first reference value, for example 120 km/h, the coolant temperature is set to 90°Celsius, and if the speed of the vehicle exceeds a second reference value, for example 160 km/h the coolant setpoint temperature is set to 80°Celsius.

In the last stage of the decision cascade the coolant setpoint temperature TMSoll4 which is evaluated after the vehicle speed is evaluated and determined using the temperature of the external air. In this way, the previously obtained coolant setpoint temperatures can ultimately be overridden if extreme environmental conditions, for example extreme cold, occur, and a coolant setpoint temperature TMSoll5 which is to be

ultimately applied can be determined, said coolant setpoint temperature TMSoll5 being predefined as a setpoint variable to the actuating means for the fan 4 and the three-way thermostat 11. If the external temperature exceeds a first reference value of, for example, 12°Celsius, the temperature is not lowered by the last stage of the decision cascade. The coolant setpoint temperature is adapted to the external temperature when the temperature drops below the first reference value, of for example 12°Celsius, to a coolant setpoint temperature of 90°Celsius. If the external temperature drops further and if it drops below a second reference value, of for example minus 15°Celsius, the coolant setpoint temperature is set to 105°Celsius independently of the other influencing variables.

The coolant setpoint temperature TMSoll5 which is ultimately present after the fifth stage is retained as a setpoint variable for the actuation of the fan 4 and of the three-way thermostat 11 for a minimum time period, of for example 100 seconds, independently of the input signals 21, 22, 23, 24, 25, 26 and of the speed of the vehicle. This hold function can be realized, for example, with a holding element or a program weighting loop. In the signal flowchart in figure 2, the hold function of the coolant setpoint temperature which is determined is symbolized by a timing holding element 29.

Fig. 3 illustrates a further feature of the invention, specifically the addition to the thermal management of the internal combustion engine of a fallback level if the previously described control algorithm fails. The basis of the fallback level is a characteristic signal disable which is checked by the following actuation means for the fan 4 and the three-way thermostat 11.

This characteristic signal is generally a fault flag which is set if a fault was determined in the process to be checked. If the fault flag is set, possible coolant setpoint temperatures which are determined with the control algorithm from fig. 2 are not taken into account by following controllers. The cooling system of the internal combustion engine is then either operated continuously at maximum cooling power, or the coolant temperature is set in a merely temperature-controlled fashion in the conventional way using a redundantly provided PID controller if one is present.

The fault detection act according to the exemplary embodiment in fig. 3 is carried out here by programming means using the Failsafe Program Module by monitoring the relevant data signals, by monitoring the coolant temperature and by means of a program fault decision and by setting the disable fault flag using the module TM_disable. The fault decision can alternatively be taken here as soon as either the coolant temperature exceeds a predefined critical reference value, of for example 108°Celsius, or as soon as a data signal which is not present or a data signal which is not permitted is defined by the Failsafe signal flow monitoring means. The monitoring of faults can also be extended to monitoring the control units of the engine electronics ME. The control units have self-test routines which make available fault signals which can also be monitored using the module for monitoring the signal flow. If a fault is detected by the signal flow monitoring means, a fault characteristic signal is sent to the decision stage TM_disable. The fault is then evaluated in the decision stage by means of the transmitted fault identifier and the decision is taken as to whether to set a fault flag or not.